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Further Laboratory Studies of Friction in TFE Slide Surface of a Bridge Bearing

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Abstract:	A laboratory study relating to four aspects of the friction in a lubricated TFE-stainless steel slide surface of a bridge bearing is described. The four aspects are the repeatability of test data from friction tests, means of reducing the initial coefficient of friction, effects of contamination of the lubricant and effects of eccentricity of load. It is found that appreciable scatter occurs in the data from friction tests and that neither precycling of the TFE-stainless steel interface at a low contact pressure nor lubrication of the stainless steel surface, in addition to the TFE surface, reduces the initial coefficient of friction. Further, it is shown that the coefficient of friction is increased significantly by the presence of a relatively small amount of Portland cement in the lubricant and to a lesser degree by eccentricity of loading.
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1 INTRODUCTION

Tetrafluoroethylene (TFE) is used to provide sliding surfaces in bridge bearings due to its low friction properties as well as its chemical inertness and resistance to water absorption and weathering. Usually the surface mating with the TFE is stainless steel.

Design requirements for TFE sliding surfaces in bridge bearings are contained in the Ontario Highway Bridge Design Code (OHBDC) [4]. In order to refine these requirements, which are based largely on current practices in Ontario and Europe, the Ministry of Transportation of Ontario (MTO) has undertaken a research program relating to TFE sliding surfaces in bridge bearings in Ontario.

This report summarizes the laboratory testing carried out at Queen's University under the sponsorship of MTO on Phase II of a research project entitled "TFE Sliding Surfaces in Bridge Bearings". Earlier work, carried out in Phase I of the project, has been described in two reports [1,2]. These reports presented the state-of-the-art of TFE slide surfaces and described a test program aimed at investigating some of the more significant parameters affecting the coefficient of friction in a TFE-stainless steel interface.

The following areas, which were identified in Phase I as requiring further study, are investigated in Phase II :

(a) repeatability of test data

(b) reduction of the initial coefficient of friction

(c) contamination of the lubricant

(d) eccentricity of loading

Chapter 2 of this report summarizes the findings from Phase I, while the laboratory test program of Phase II is described in Chapter 3. Test results are presented and described in Chapter 4. Conclusions are drawn and recommendations are given in Chapter 5.

2 SUMMARY OF PHASE I STUDIES

The state-of-the-art report by Campbell and Kong [2] identified 14 parameters which affect the coefficient of friction of TFE sliding on a metallic plate. These parameters are dimpling and lubrication of the TFE, contact pressure, sliding speed, eccentric loading, temperature, creep, roughness of the mating surface, type of TFE, attachment of the TFE to the backing plate, surface contamination, length of the travel path, load and travel history, specimen size and wear of the TFE. The influences of these various parameters have been discussed in detail in [2] and are summarized in [1].

A test program to investigate the influences of four of the above parameters, namely contact pressure, temperature, sliding speed and roughness of the mating surface is described in [1]. Test data are presented and analyzed. The coefficient of friction was found to increase with an increase in sliding speed and roughness of the stainless steel mating surface and with a decrease in contact pressure and temperature. It was concluded that the values of the coefficient of friction given in the OHBDC [4] follow the proper trends and are conservative but not unduly so at low temperatures and at high sliding speeds with a rough mating surface.

It was also found that a relationship between the coefficient of friction, μ, and the contact pressure, P, on the TFE of the form

$$\mu = Q P^{n-1}$$

where Q and n are parameters which are dependent on the test conditions, gave a reasonably good fit to the test data. However, more data are required in order to establish values of the parameters Q and n.

3 LABORATORY TEST PROGRAM

3.1 GENERAL

Two areas requiring additional study were identified from the results obtained in the laboratory testing program of Phase I. These were the repeatability of the test data and means of reducing the initial coefficient of friction of the TFE. In the Phase I study, scatter of the test data, particularly that obtained in the low temperature tests, was evident, while the value of the coefficient of friction during initial movement in the TFE-stainless steel interface was found to be as high as five times that after 50 cycles of movement.

The sliding surface in a bridge bearing in service may be subjected to contamination from its environment. The literature indicates that contamination of the lubricant increases the coefficient of friction in the sliding interface, but no quantitative data relating specifically to this effect on the frictional properties or related wear of TFE appear to exist.

Accommodation of rotation of the superstructure of a bridge relative to its substructure results in eccentric loading patterns within the components of a bearing. Eccentricity produces moment which induces additional edge pressure on the TFE at the sliding surface. Reduction of pressure on an edge may cause uplift resulting in the TFE being squeezed out of the interface, while increased pressure may cause flattening of the TFE and closure of the grease dimples. This will impair the performance and reduce the life of the bearing through increased wear of the TFE. Test data relating specifically to the effect of eccentricity of load on the coefficient of friction of TFE do not appear to be readily available.

3.2 TEST PROGRAM

A test program was undertaken to study the following with respect to the friction developed in a lubricated TFE-stainless steel interface:

(a) repeatability of test data

(b) reduction of the initial value of the coefficient of friction

(c) contamination of the lubricant

(d) eccentricity of loading

Unless otherwise stated all tests were carried out at room temperature (20° C) in an existing test rig using dimpled TFE lubricated with Molykote 44 grease and sliding on a No. 8 finish stainless steel plate at a speed of 1 mm/s. A total of 200 cycles of movement at 40 mm per cycle was completed in each test after the interface was preloaded at zero eccentricity, except in the tests where an eccentricity of load was present, for a period of 12 hours. A diagrammatic representation of the testing rig is shown in Fig. 3.1. Further details of rig are given in [1].

3.2.1 Repeatability of test data

Tests were carried out using the same procedure as in the test program described in [1]. In each test a 75 mm diameter disc of 4.5 mm thick dimpled TFE, recessed to a depth of 2.5 mm in a steel backing plate, was loaded to a contact pressure of 30 MPa. This is the pressure level specified by the OHBDC [4] for the TFE slide surface in a bridge bearing under dead load. After a sustained load period of 12 hours, the TFE-stainless steel interface was subjected to 200 cycles of movement. Seven tests were conducted, four at 20° C and three at −27° C These tests have been identified using the prefix REP. The tests at 20° C served as controls for the entire test program.

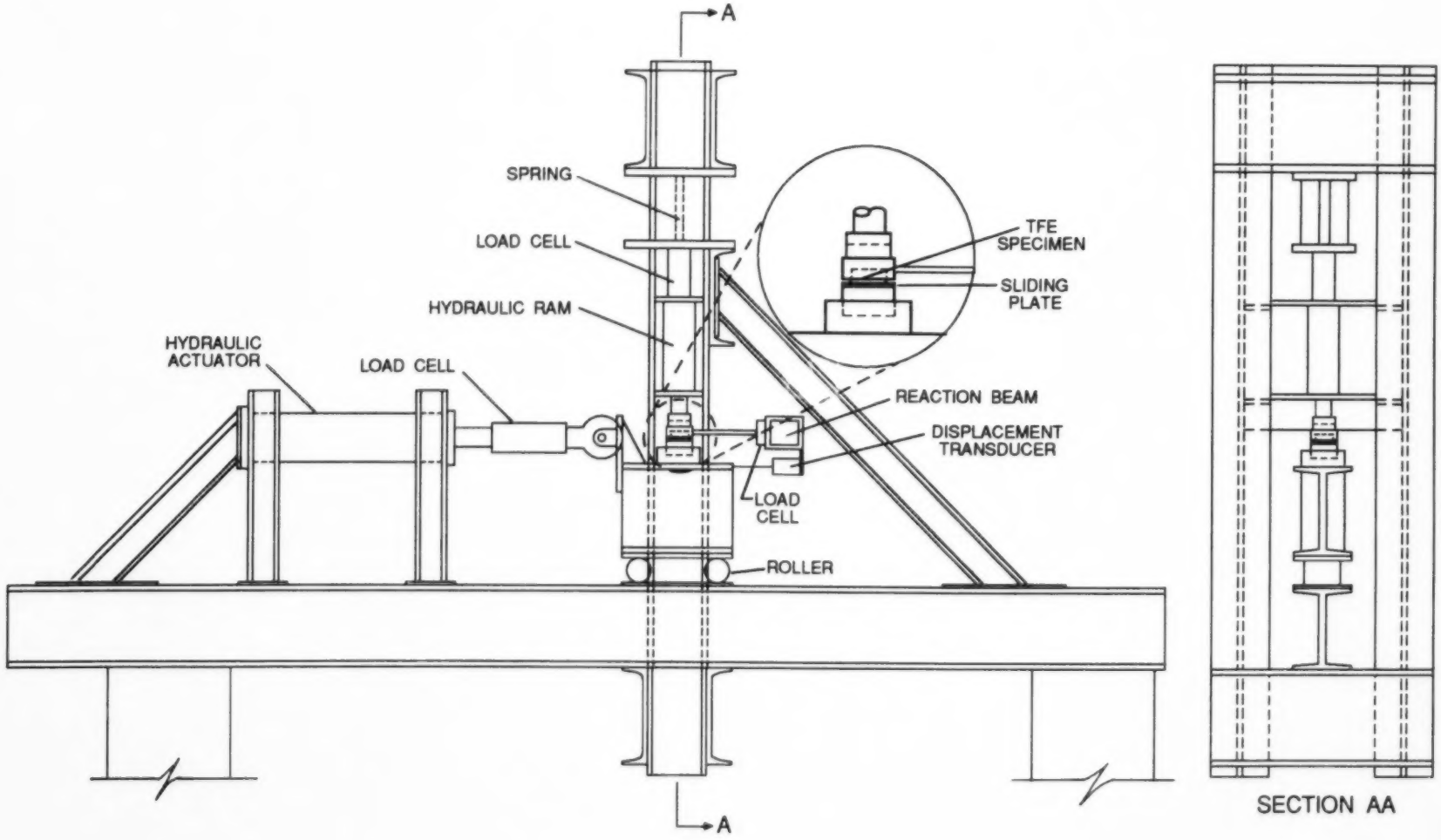


Fig. 3.1 Diagrammatic representation of testing rig

3.2.2 Reduction of the initial value of the coefficient of friction

Two approaches, namely precycling of the TFE-stainless steel interface and lubricating of both the stainless steel and TFE surfaces (double lubrication), were investigated. The influence of dwell of load, which is defined as a hiatus in the sliding movement, on the effects of precycling was also studied.

The TFE-stainless steel interface was preloaded to a level of 5 MPa and after a dwell period of one hour, subjected to 20 cycles of movement. The low pressure level of 5 MPa was chosen in order to limit the magnitude of the load necessary to induce this pressure in the interface of an actual bearing. Limiting the load is an important consideration if precycling were to be considered for practical application, since this would reflect directly on the load capacity of the required equipment. The dwell period of 1 hour was selected arbitrarily, while previous tests [1] have indicated that the coefficient of friction reaches a stable value after approximately 20 cycles of movement. Five tests were carried out, in which an interface preconditioned as above, was loaded to 30 MPa and then subjected to 200 cycles of movement after different dwell periods. In the five tests these dwell periods were 0, 12, 24, 48 and 96 hours. This range of dwell periods was selected since it has been reported [2] that the coefficient of friction for TFE increases with dwell period up to about 24 hours dwell of load and then levels off. These tests have been identified using the prefix PRE with Test PRE-1 having a dwell period of zero hours and Test PRE-5 having the maximum dwell period of 96 hours.

The influence, during the initial movement, of having lubricant applied to the stainless steel plate in the area where the TFE slides during the first cycle, was investigated. Three tests were carried out with Molykote 44 grease applied over the relevant area of the stainless steel plate, in addition to that applied to the TFE surface. Lubricant was applied only to the TFE surface in all Phase I tests and in all other Phase II tests. The lubricant was smeared on the stainless steel surface using a cotton swab. The double lubricated interface was loaded to 30 MPa and

subjected to 200 cycles of movement after a dwell period of 12 hours. These tests have been identified using the prefix LUB.

3.2.3 Contamination of the lubricant

Twelve tests were carried out where, prior to starting a test, the lubricant was contaminated to different degrees using Type 30 Portland cement. Contaminations ranging from light to heavy were classified by visual observation of the cement on the lubricated surface of the TFE. The cement was sprinkled unto the TFE through a 500 sieve subsequent to applying the lubrication. The degree of contamination (DOC) was defined as the weight of the contaminant in the lubricant per unit surface area of the TFE. The weight of the contaminant was determined by weighing the lubricated TFE specimen before and after applying the cement. The degree of contamination (DOC) present in each test is shown in Table 4.3 and ranged from 0.239 mg per mm^2 to 0.0009 mg per mm^2 . The specimen was subjected to 200 cycles of movement in each test. These tests have been identified using the prefix CNT.

A further two tests were undertaken to study possible infiltration of external contamination into the sliding interface during the cyclic movement. The stainless steel plate was contaminated artificially outside the initial contact area using Type 30 Portland cement. The contamination was applied at intervals of 25 cycles of movement and a total of 200 cycles of movement was undertaken in each test. These tests have been identifed using the prefix INF, with Test INF-1 having an eccentricity of load of zero on the interface and Test INF-2 having a 10 mm eccentricity.

3.2.4 Eccentricity of loading

Six tests were conducted on TFE specimens under an average pressure of 30 MPa but having an eccentricity of load. Three of the tests had an eccentricity of 5 mm and in the other three tests the eccentricity was 10 mm. A load having an eccentricity of 10 mm acts outside the

middle quarter of the 75 mm diameter TFE disc and results in unloading at the edge of the disc. The eccentricity of load was achieved in the test rig by a minor modification of the steel backing plate which contained the TFE. These tests have been identified using the prefix EXC.

4 ANALYSIS OF TEST DATA

4.1 GENERAL

Test data are examined in this chapter with reference to each of the four areas of investigation. Values of the static coefficient of friction only are given, since the static coefficient of friction is always greater than the dynamic coefficient of friction.

4.2 REPEATABILITY OF TEST DATA

Results from each of the four repeatability tests (REP-1 to REP-4) at room temperature (20° C) are given in Fig. 4.1(a). The same trend is exhibited in each test in that the value of the coefficient of friction reduces rapidly from the initial value and stabilizes after about 20 cycles. The value of the coefficient of friction after 200 cycles ranged from 0.0035 to 0.0021 in the four tests with a mean of 0.0028 and a standard deviation of 23 percent of the mean.

Results from each of the three repeatability tests (REP-5 to REP-7) at −27° C are given in Fig. 4.1(b). Again the coefficient of friction reduces over the early cycles, reaches a minimum after about 30 cycles but then tends to increase again. The increase is most pronounced in Test REP-5. The value of the coefficient of friction after 200 cycles ranged from 0.023 to 0.044 in the three tests with a mean of 0.033 and a standard deviation of 32 percent of the mean. The larger scatter at −27° C is consistent with the trend observed from the low temperature tests in Phase I of the study [1] and indicates that the coefficient of friction of TFE appears to be more variable at lower temperatures.

It may be concluded that appreciable scatter will occur in the data from friction tests on TFE. Consequently, a number of tests must be conducted under the relevant conditions in order to establish a realistic value of the coefficient of friction.

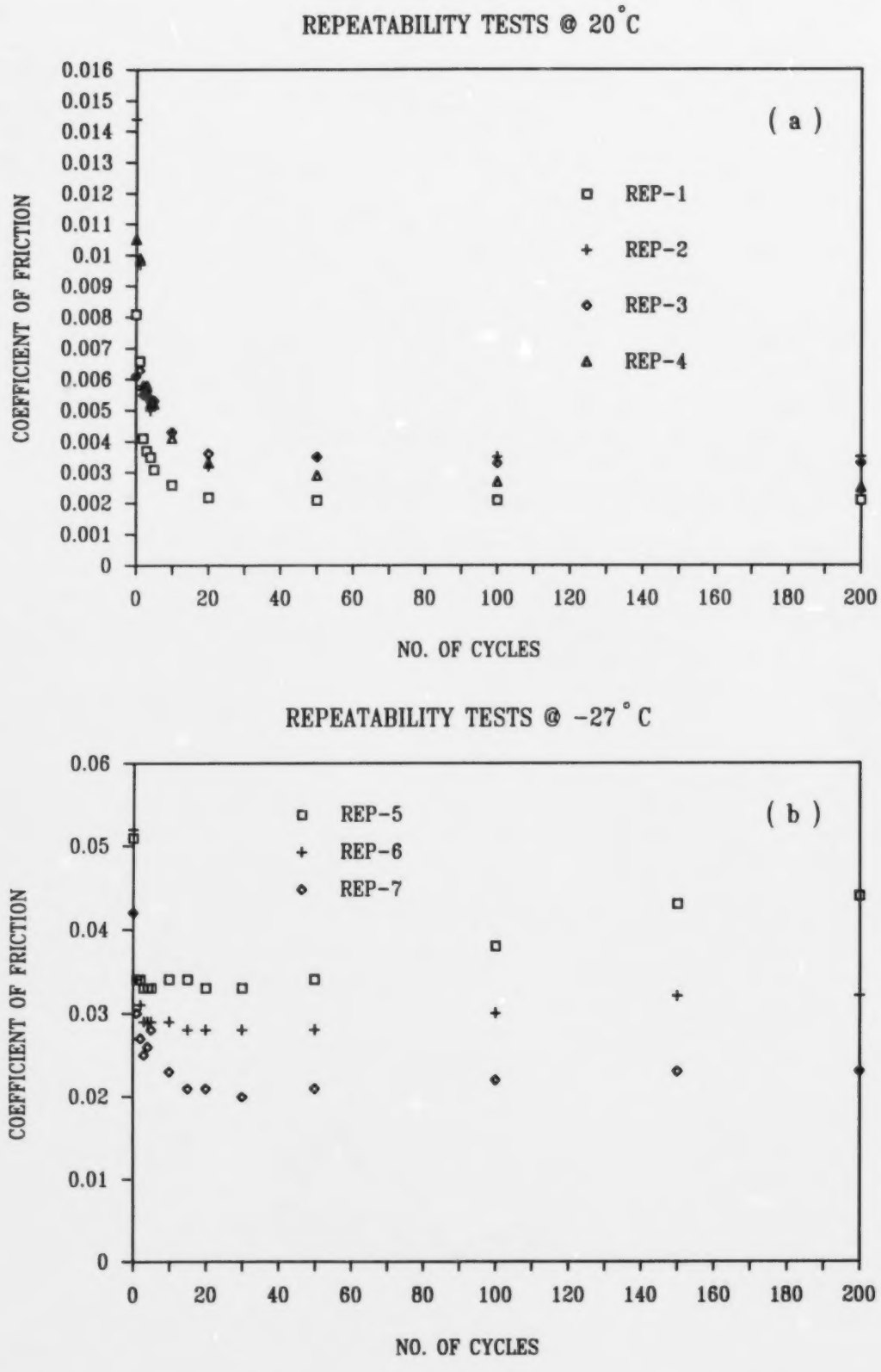


Fig. 4.1 Results from repeatability tests

4.3 REDUCTION OF THE INITIAL VALUE OF THE COEFFICIENT OF FRICTION

Results from the five precycling tests (PRE-1 to PRE-5) and the three double lubricant tests (LUB-1 to LUB-3) are given in Fig. 4.2 and Fig. 4.3, respectively. The variation in the coefficient of friction with number of cycles of movement, as obtained using average values from the four repeatability tests at 20° C, is also shown for comparison in Figs. 4.2 and 4.3.

Figure 4.2 shows that comparable results were obtained from all five of the precycling tests, indicating that dwell period did not have any significant effect on the value of the coefficient of friction. The dwell period for each test is indicated in Fig. 4.2. Further,it can be seen from Fig. 4.2 that the coefficient of friction in the precycling tests is slightly higher than the average value from the repeatability tests at 20° C.

Variable results were obtained from the three LUB tests as shown in Fig. 4.3. It can also be seen in Fig. 4.3 that the coefficient of friction is higher than the average value from the repeatability tests at 20° C in Tests LUB-1 and LUB-2 and comparable in Test LUB-3.

The initial values of the coefficient of friction and the values after 50 cycles of movement, as obtained from precycling tests and the double lubricant tests, are compared with values from tests REP-1 to REP-4 in Tables 4.1 and 4.2, respectively. Values of the coefficient of friction after 50 cycles were used since these were found to be representative values in the Phase I study.

From Table 4.1 it can be seen that the values of the initial coefficient of friction are variable in all the three series of tests and that no significant change in the values, from those in the REP tests, results from precycling or from double lubrication. Table 4.2 shows that there is no significant difference in the value of the coefficient of friction after 50 cycles in the three series of tests.

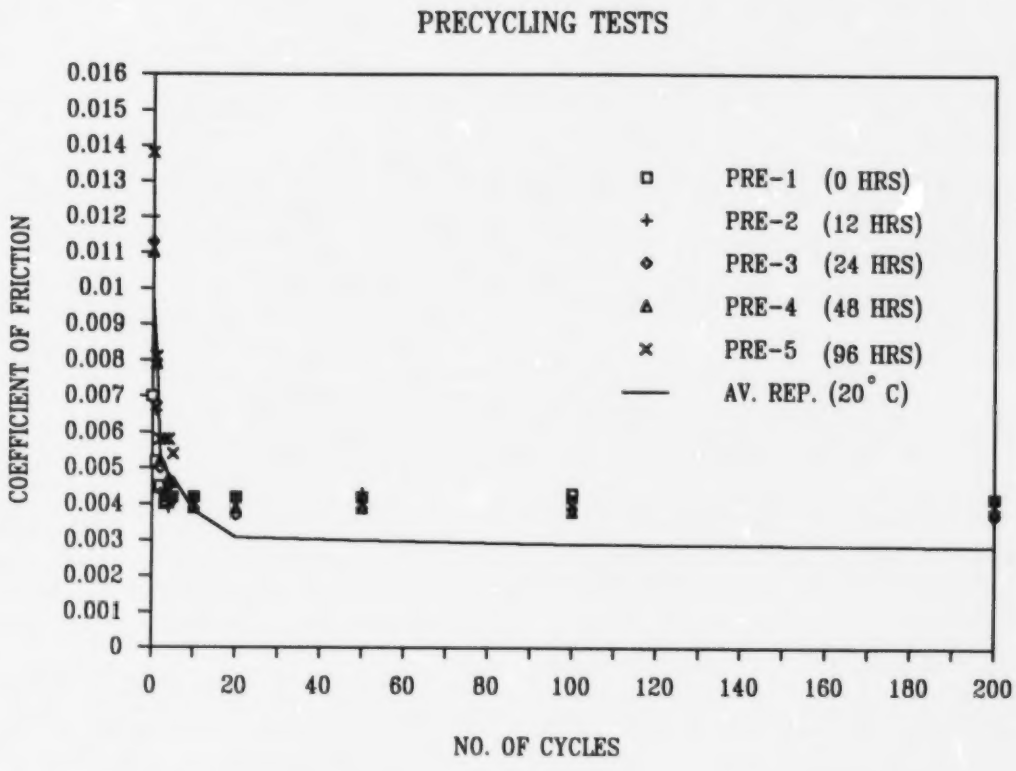


Fig. 4.2 Results from precycling tests

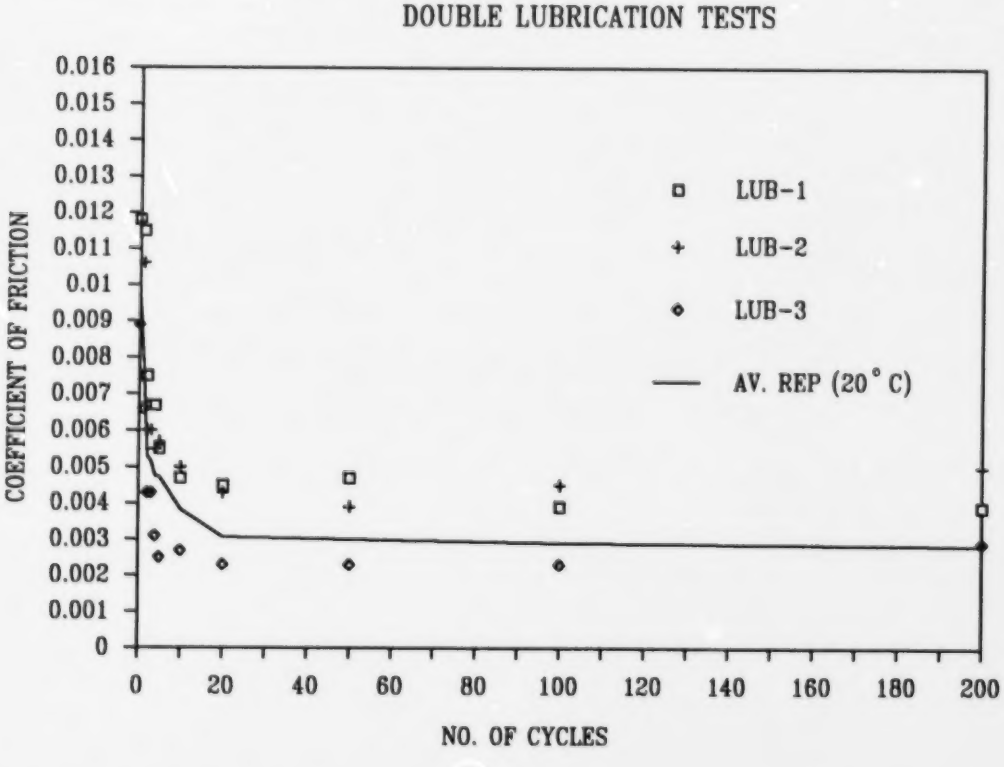


Fig. 4.3 Results from double lubrication tests

Table 4.1 Initial coefficient of friction

TEST	C.O.F.	TEST	C.O.F.	TEST	C.O.F.
LUB-1	0.0118	PRE-1	0.0070	REP-1	0.0081
LUB-2	0.0117	PRE-2	0.0120	REP-2	0.0144
LUB-3	0.0089	PRE-3	0.0113	REP-3	0.0061
		PRE-4	0.0110	REP-4	0.0105
		PRE-5	0.0138		

Table 4.2 Coefficient of friction after 50 cycles

TEST	C.O.F.	TEST	C.O.F.	TEST	C.O.F.
LUB-1	0.0042	PRE-1	0.0042	REP-1	0.0021
LUB-2	0.0039	PRE-2	0.0043	REP-2	0.0035
LUB-3	0.0023	PRE-3	0.0039	REP-3	0.0035
		PRE-4	0.0039	REP-4	0.0029
		PRE-5	0.0042		

It may be concluded that precycling at a low contact pressure or the use of double lubrication does not significantly influence the value of the initial coefficient of friction in a lubricated TFE-stainless steel sliding interface.

4.4 CONTAMINATION OF THE LUBRICANT

Data from each of the twelve contamination tests (CNT-1 to CNT-12) are given in Fig. 4.4 in the form of plots of coefficient of friction versus number of cycles of movement. Pertinent results are summarized in Table 4.3 and Fig. 4.5, which both show initial and peak values of the

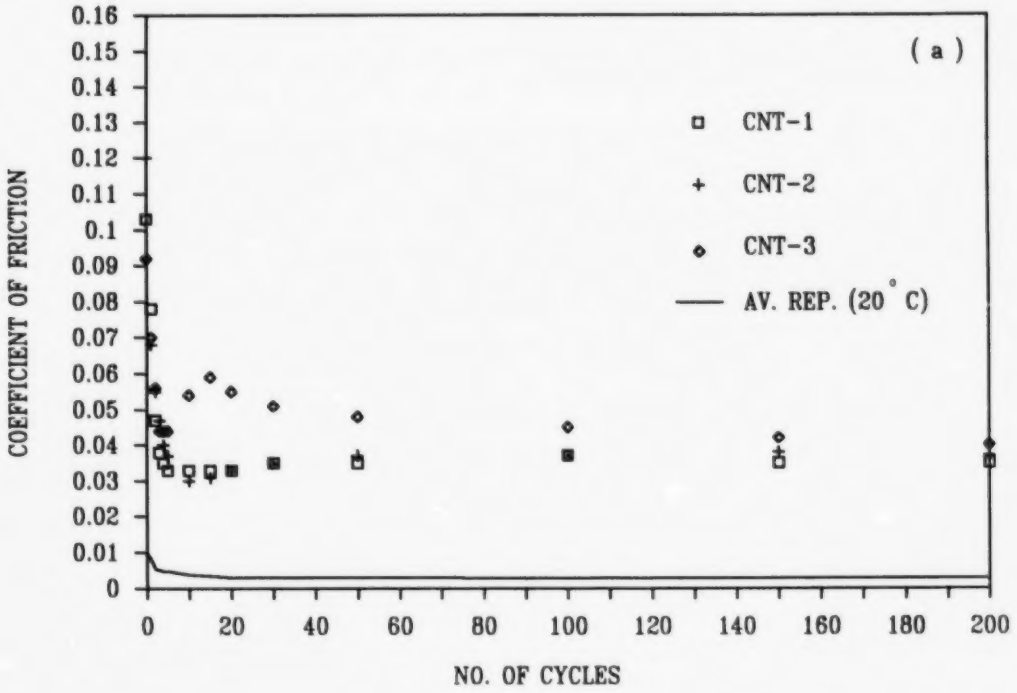
coefficient of friction, as well as values after 200 cycles of movement. The value after 200 cycles was not available in Test CNT-8 due to a malfunction of the data acquisition system.

Table 4.3 Summary of CNT test results

Test No.	*DOC** mg/mm^2	Coefficient of friction			
		Initial	Peak	@ Cycle	200 cycles
CNT-1	0.1440	0.1030	0.1030	Init.	0.0350
CNT-2	0.2390	0.1200	0.1200	Init.	0.0370
CNT-3	0.0710	0.0920	0.0920	Init.	0.0400
CNT-4	0.0330	0.0620	0.0620	Init.	0.0310
CNT-5	0.0330	0.0530	0.0550	15	0.0280
CNT-6	0.0160	0.0220	0.0510	15	0.0310
CNT-7	0.0070	0.0190	0.0330	15-30	0.0290
CNT-8	0.0022	0.0170	0.0330	15-30	-
CNT-9	0.0013	0.0100	0.0130	15-20	0.0066
CNT-10	0.0018	0.0110	0.0250	20	0.0190
CNT-11	0.0044	0.0130	0.0340	20	0.0250
CNT-12	0.0009	0.0097	0.0097	Init.	0.0043

* Degree Of Contamination

From Fig. 4.4(a) it can be seen that, in the tests with high contamination (CNT-1 to CNT-3), the coefficient of friction was a maximum during the initial movement, reduced to a minimum after 5 to 10 cycles, increased slightly over the next 30 to 40 cycles and then remained fairly constant up to 200 cycles. The relatively high values of the coefficient of friction suggest that the lubricant



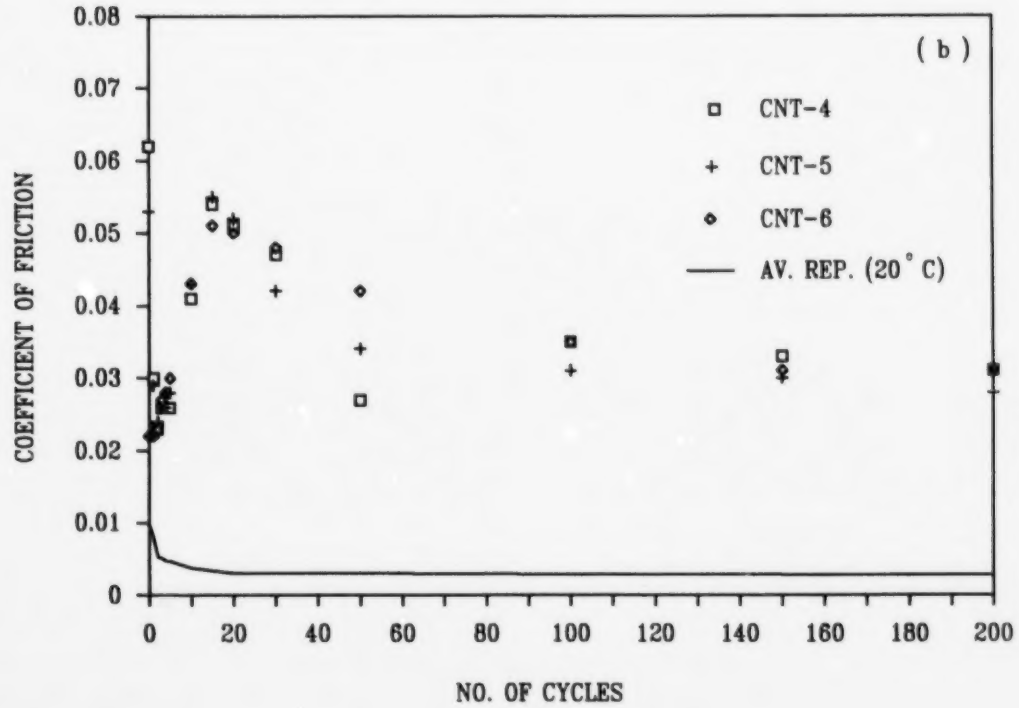
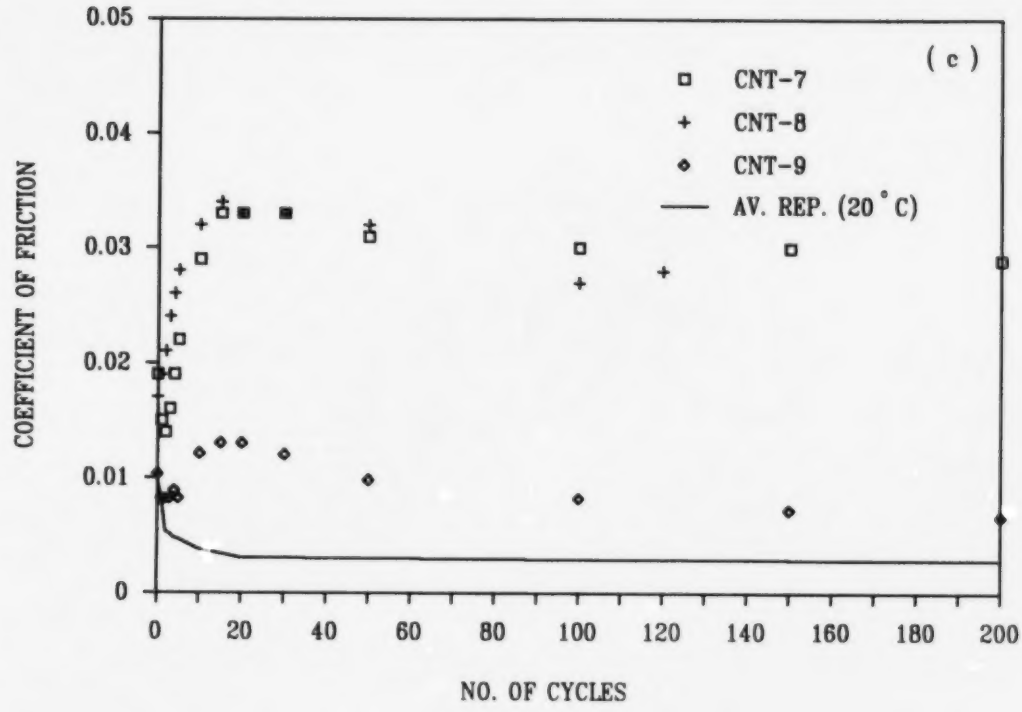


Fig. 4.4 Results from contamination tests



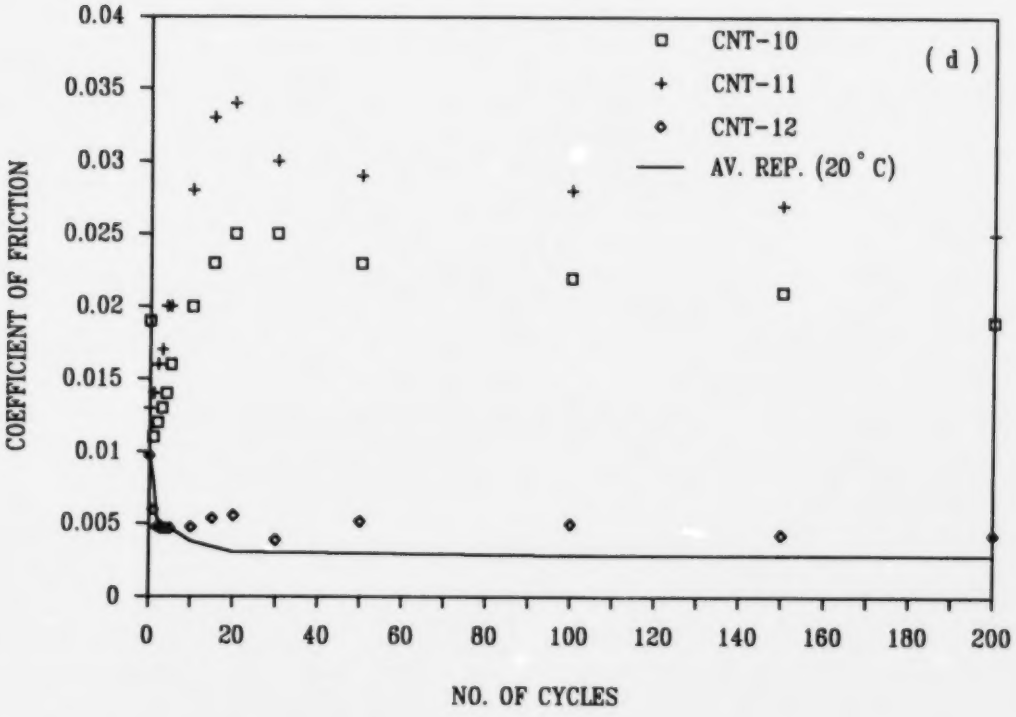


Fig. 4.4 (continued)

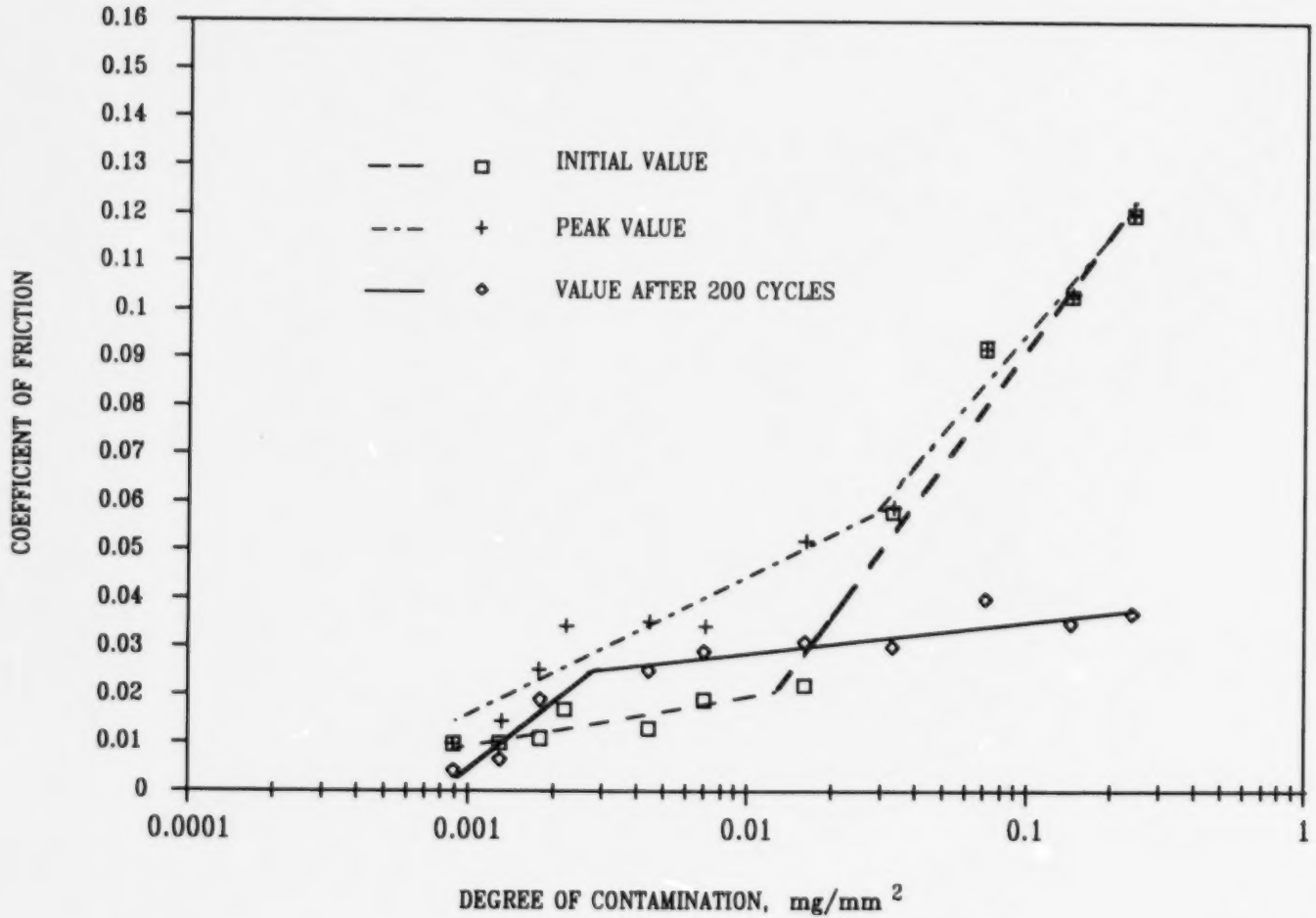


Fig. 4.5 Variation of coefficient of friction with degree of contamination

was ineffective in these three tests. In the remaining tests, with the exception of CNT-9 and CNT-12, as can be seen in Figs. 4.4(b), (c) and (d), the value of the coefficient of friction generally increased during the early cycles of movement, reached a maximum after about 20 cycles and then decreased to a reasonably stable value after about 70 cycles. This trend suggests that the lubricant was effective during the first 20 cycles but then became virtually ineffective. In Tests CNT-9 and CNT-12, which had the two lowest DOC values, significantly lower values of the coefficient of friction were obtained, indicating that the lubricant remained effective throughout. However, the values of the coefficient after 200 cycles in these two tests were higher than the average value from the REP tests at 20° C, indicating that even a small amount of contamination has a significant influence on the coefficient of friction.

The initial value, the peak value with the cycle number at which it occurred, and the value of the coefficient of friction after 200 cycles for each of the twelve CNT tests are given in Table 4.3 and in Fig. 4.5, which shows a plot of the coefficient of friction versus the degree of contamination (DOC) on a logarithmic scale. The trend in each of the three values is indicated by a bilinear relationship determined by separate regression analyses of the data on either side of the DOC value where a distinct change in the rate of variation of the coefficient of friction was apparent. The initial values and peak values decrease rapidly with DOC for values of DOC in excess of 0.014 mg/mm^2 and 0.028 mg/mm^2, respectively, and less rapidly for values of DOC below these levels. The values after 200 cycles increase rapidly with DOC for DOC values up to 0.003 mg/mm^2, after which the rate of increase is significantly reduced. All three values approach those typical for an uncontaminated interface at DOC values of 0.0009 mg/mm^2.

Figure 4.5 also shows that the coefficient of friction after 200 cycles was in the region of 0.03 to 0.04 when the DOC value was greater than 0.01mg/mm^2. Since the coefficient of friction of unlubricated TFE has been reported [2,5] to be in the region of 0.04, it appears that the lubricant is ineffective for high values of DOC. The absence of lubrication in the interface was confirmed by visual inspection of the specimen after testing. Figure 4.6 shows a comparison

between a lubricated TFE specimen prior to testing and the TFE specimen from Test CNT-1 after testing. The flaky, black coating which formed on TFE surface during the test can be seen. Significant wear of the TFE occurred in test CNT-1. The wear is characterised by deposits of TFE flakes at each end of the travel path (Fig. 4.7) and by a reduction in the size of the dimples in some areas as can be seen in Fig. 4.6. Wear of the TFE was apparent in the three tests with high DOC values.

The abrasive effect of the contaminant in the interface during the cyclic movement is apparent in Fig. 4.8, which shows the stainless steel plate used in Test CNT-3. Surface roughness measurements made perpendicular to the direction of movement in the contact area indicated that the surface roughness had increased to 0.2 μm from the value of 0.015 μm prior to the test. However, in the direction of travel there was only a slight increase (0.03 μm to 0.04 μm) in surface roughness.

It may be concluded that the coefficient of friction of a lubricated TFE-stainless steel interface is increased by a relatively low amount of contamination in the form of Portland cement. Consequently, bearings incorporating a lubricated TFE slide surface should be assembled in a dust free atmosphere and should not be taken apart on site.

Data from the two infiltration tests (INF-1 and INF-2) are shown in Fig. 4.9 together with the trends in the average values of the coefficient of friction from the tests at 20° C with the relevant eccentricities, namely zero (REP series) and 10 mm (EXC series). It can be seen that the values of the coefficient of friction are similar to those for the corresponding uncontaminated lubricated interface. This indicates that very little, if any, of the contaminant infiltrated the interface during the cyclic movement. The lack of contaminant was evident from visual inspection of the interface after 200 cycles. Thus it appears that contamination of the sliding interface in a bridge bearing, located in a dust-laden environment, is unlikely even when significant eccentricity of load is present.

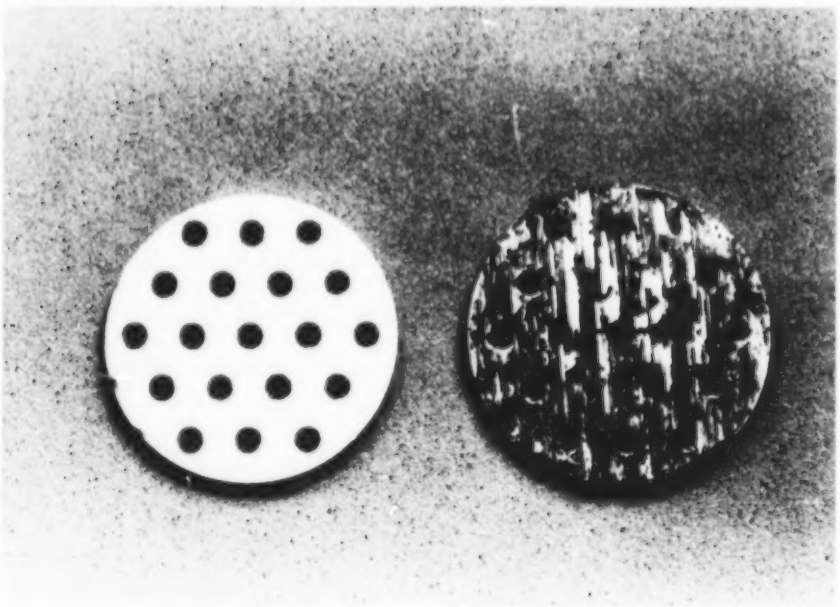


Fig. 4.6 TFE specimen before and after testing in Test CNT-1

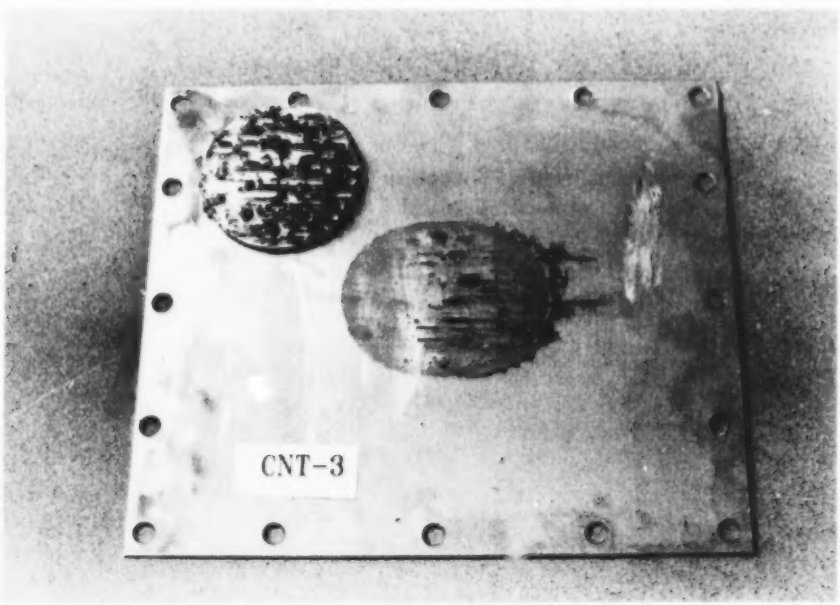


Fig. 4.7 TFE deposits in Test CNT-1

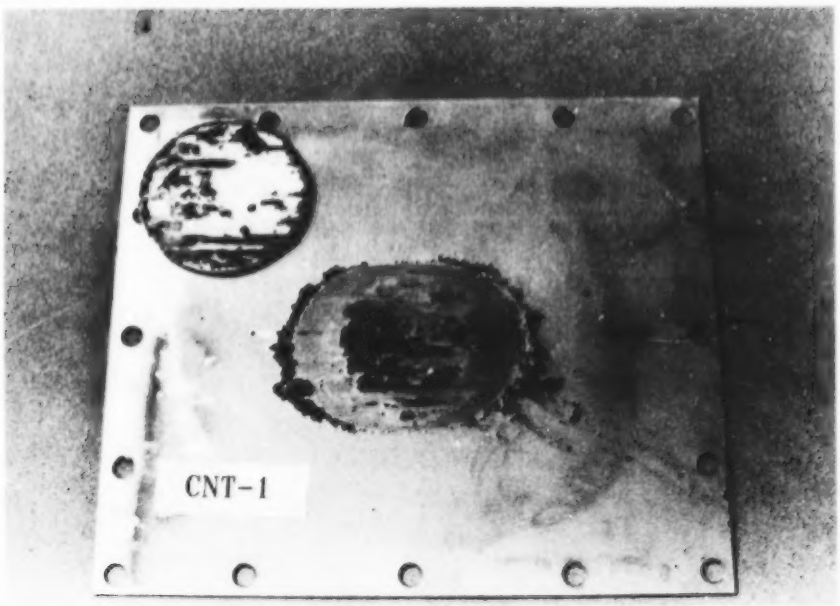


Fig. 4.8 Abrasion of stainless steel plate in Test CNT-3

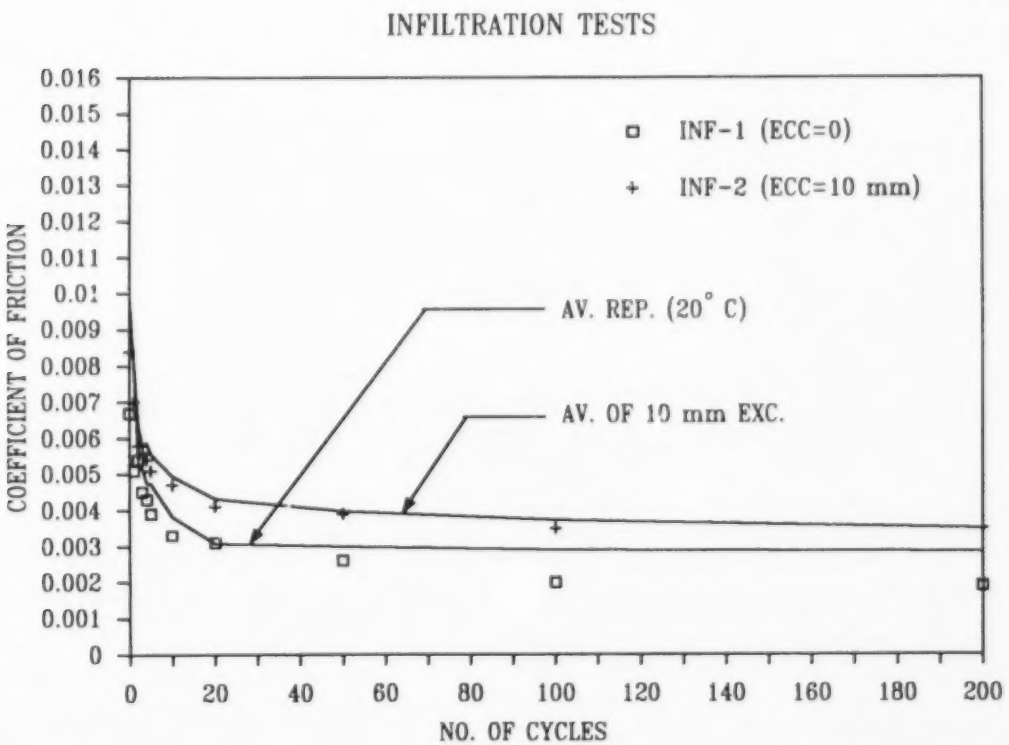
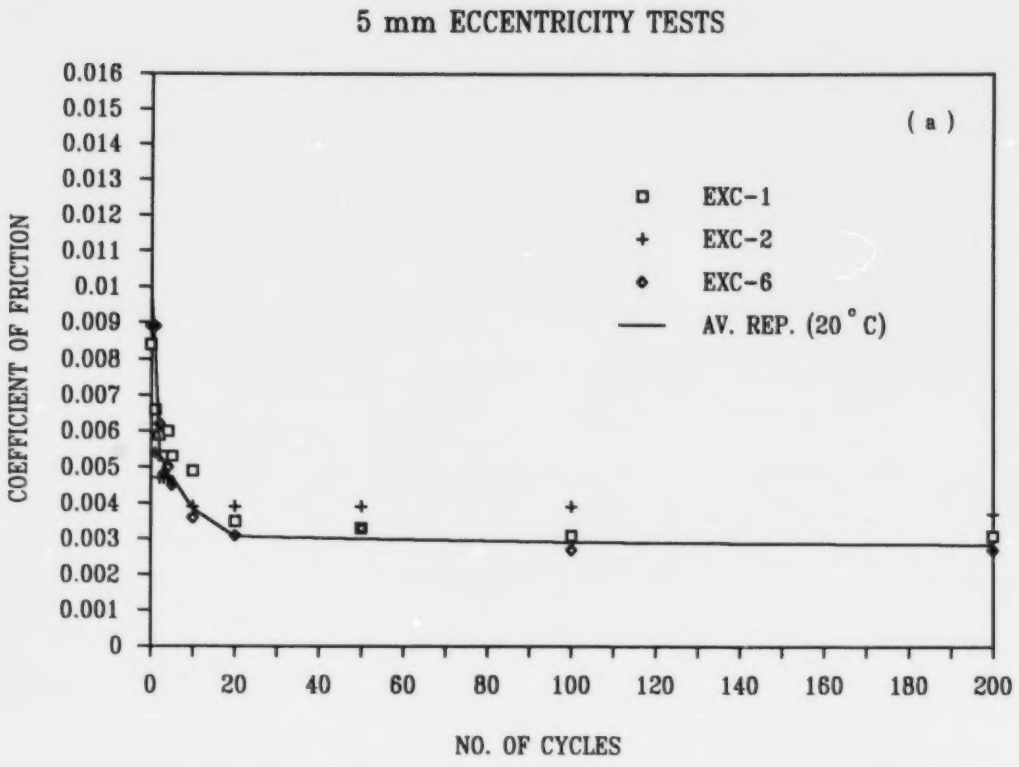


Fig. 4.9 Results from infiltration tests

4.5 ECCENTRICITY OF LOADING

Data from the three tests having an eccentricity of 5 mm (EXC-1, EXC-2 and EXC-6) are given in Fig. 4.10(a), while those from the three tests having an eccentricity of 10 mm (EXC-3, EXC-4 and EXC-5) are given in Fig. 4.10(b). The trend in the average value of the coefficient of friction from the four repeatability tests at 20° C are shown in Figs. 4.10(a) and (b) for comparison. It can be seen that the presence of eccentricity of load tends to increase the coefficient of friction slightly. No wear of the TFE was apparent but some flattening of the dimples at the higher loaded edge was obvious.



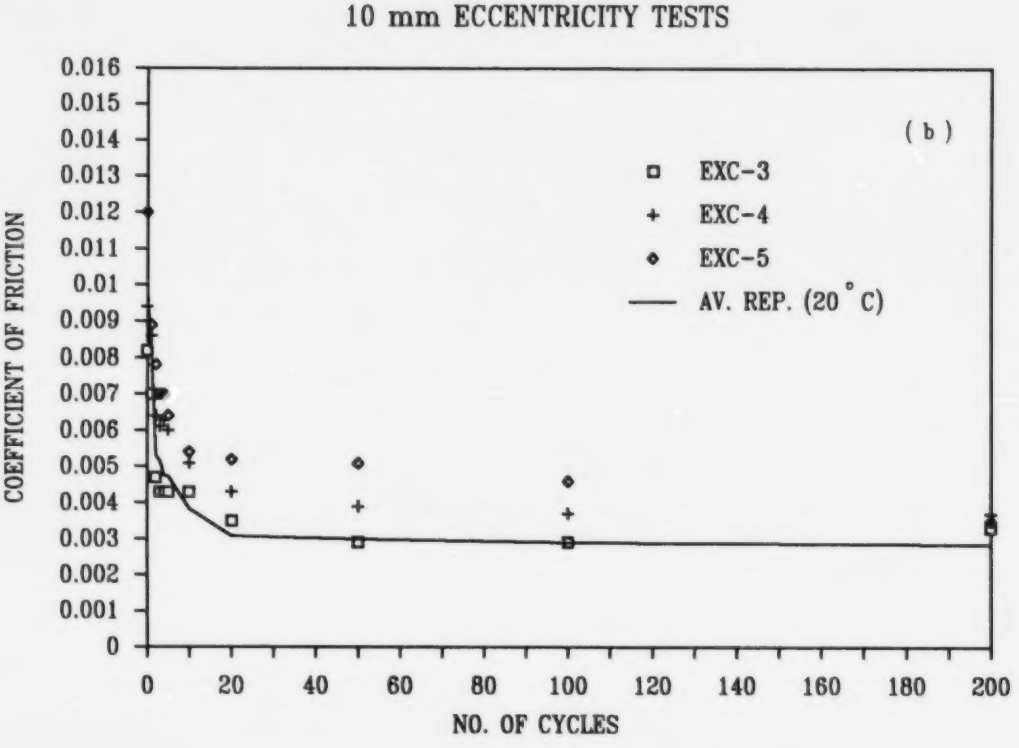


Fig. 4.10 Results from eccentricity tests

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the data obtained from the test program, the following conclusions may be drawn for a lubricated TFE-stainless steel interface:

1. Appreciable scatter occurs in the data from the friction tests. The scatter is greater at lower temperatures.

2. Precycling at a low contact pressure or use of double lubrication does not influence the value of initial coefficient of friction.

3. The coefficient of friction is increased when the interface is contaminated with a relatively low amount of Portland cement.

4. Contamination of the interface of a bridge bearing in service in a dust-laden environment is unlikely, even when significant eccentricity of loading exists.

5. Eccentricity of loading tends to increase the coefficient of friction.

5.2 RECOMMENDATIONS

The following recommendations are made:

1. A number of tests must be conducted under the relevant conditions in order to establish a realistic value of the coefficient of friction.

2. Bearings incorporating a lubricated TFE-stainless steel slide surface should be assembled in a dust free environment and should not be opened on the bridge site.

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